THE ERUPTIVE ROCKS OF MEXICO.

PART III of the recently published *Bosquejo Geológico de México* consists of a study by Ezequiel Ordoñez of the eruptive rocks of Mexico.[1] This may be regarded as the most complete and satisfactory summary of the present state of knowledge of this subject which has yet been published.

Humboldt's *Essay on New Spain* contains many observations on the rocks of the silver-bearing regions of Mexico which are made with great accuracy and fullness of detail. But the science of petrography has made many advances since Humboldt's day. It is no longer sufficient to describe rocks as primitive schists and porphyries nor can altered andesites and tuffs be disposed of as graywackes. These terms are, however, an improvement on *saxum metalliferum*, the name by which many of the rocks were earlier known. Modern geologists, moreover, can hardly agree with the great *savant* in his conclusion that the richness of veins is entirely independent of the nature of the rocks which the veins traverse. The great similarity found among the rocks of the silver-bearing regions of Mexico and their resemblance to those of Nevada and Germany in which similar veins occur, indicates that a definite relation probably exists between rock and vein.

Humboldt's work, however, remains about the only authoritative one on the rocks of Mexico as a whole, which can be consulted. The names which he applied to the rocks and the opinions which he expressed regarding their origin will be found to be those prevailing in Mexico today. Since the publication of his work studies of single rocks or of limited regions have been published, but little, if any, attempt has been made to correlate observations. There is room, therefore, for a comprehensive study of the kind made by Señor Ordoñez.

[1] *Boletin del Institute Geológico de México*, Nums. 4, 5, y 6, Mexico, 1897.

In his paper the rocks are described in terms of modern petrography and with as much detail as the plan of the sketch permits. This plan he states to be an endeavor to give some idea of the petrographic provinces of the country, indicating for each one of them the predominating species, without entering into minute details concerning the extent of each. Commencing with the pre-Cretaceous rocks, the granites, pegmatites, granulites, syenites, and dicrites of this age are described in order in their respective provinces. The post-Cretaceous rocks are discussed next, beginning with the granites and passing on in order through the granulites, diorites, diabases, andesites, dacites and rhyolites. Then are taken up what are called the andesites of the second invasion, which were produced by the volcanic eruptions which began near the end of the Tertiary period. Finally the labradorites and basalts which largely characterize the latest eruptions are considered. Of especial interest is the account given of the rocks of the great silver-bearing regions of Zacatecas, Guanajuato and Pachuca, regions which though widely separated, the author finds to present remarkable uniformity as to kinds of rock and circumstances of outflow.

The work is marred by some errors, such as calling hypersthene a monoclinic pyroxene (p. 264), and the indiscriminate use of the terms amphibole and hornblende. The punctuation and paragraphing also admit of much improvement. The character of the work is as a whole, however, so admirable, that I have thought that to give a résumé of it by means of a translation of extracts would assure a wider circulation to some of the facts enunciated by Señor Ordoñez than they would perhaps otherwise attain. Of such extracts the remainder of this paper is made up.

The first indication of the part of the American continent which forms the country of Mexico, was given in Palæozoic time by the emergence of a narrow, elongated backbone which uniting with the beginnings of the Rocky Mountains to the north and of the Andes to the south constituted the foundation

of the orographic system known as the Cordillera of the Andes It is in the part of Mexico known by the name of the Western Sierra Madre that we may expect to find the principal types of ancient eruptive rocks, associated as a rule with crystalline schists and some of the earliest sedimentary rocks. The Sierra Madre extends along the Pacific coast in a general southeast-northwest direction. The western slopes, generally descending rapidly to the coast, present a notable contrast to those of the east, where numerous spurs or secondary sierras serve to support the extensive plateau of the Mesa Central. It was along the eastern slopes that the eruptive movements which in epochs later than the Cretaceous added to the relief of the Sierra Madre, chiefly occurred. Here may be seen the whole series of modern eruptive rocks, from the granites with which the eruptions clearly began, to the basalts of Quaternary time.

Considering first, then, the pre-Cretaceous rocks, we find them consisting chiefly of granites. These probably make up a large part of the mountains along the western coast of the Peninsula of Lower California, but of their exact distribution we know as yet little. In the region of Hermosillo, Sonora, in the district of Moctezuma, granite, crossed by dikes of pegmatite, occupies great tracts of country. In the district of Altar syenites and diorites replace the granite. In the region south of the state of Puebla in the districts of Chiautla and Matamoros micaceous or amphibolic granites are found passing over to gneiss or green schists. The granites are interrupted frequently by modern eruptive rocks, chiefly rhyolites and andesites, or even by stratified rocks, generally Cretaceous. In the state of Jalisco in the canton of Mascota and along the slopes of the Sierra toward the Pacific, the group of mountains of Desmoronado is formed of granites associated with quartzites and other metamorphic schists. In the central and western parts of the state of Oaxaca may be seen an extensive formation of granites and diorites, covered sometimes by breccias and modern quartzose conglomerates. These ancient masses, chiefly granites, may be followed, although interrupted by modern eruptive and sedi-

mentary rocks, nearly to the coast of the Pacific and the Isthmus of Tehauntepec.

By far the larger number of the eruptive rocks of Mexico are, however, of post-Cretaceous origin. Among the rocks which began this prolonged eruptive epoch, granites and granulites predominate, syenites are rare, andesitic diorites are abundant, and diabases sometimes occur. The different varieties, however, pass from one to another by insensible gradations, and frequently exhibit as well an ophitic or trachytic structure which leads them to resemble the true porphyrites and andesites. The frequent recurrence of these phenomena serves as a corroboration of Iddings' theory of the differentiation of magmas. The post-Cretaceous eruptive rocks which approximate in structure most nearly to those of pre-Cretaceous age, occur chiefly in the central regions of the northern and northeastern portions of the country, and are usually associated with Cretaceous limestones. The granulitic structure is that which predominates, but it may be modified to that of the granites, or even descend through the micro-granulites to the orthophyres and rhyolites.

The rocks which come after the granites have usually been known in Mexico as greenstones or green porphyries on account of their characteristic color and porphyritic appearance. To these rocks great interest has long been attached since they lodge the most important metalliferous veins of the country. A chart showing the mines of Mexico well indicates the distribution of these rocks. Each metalliferous district presents in the mass of its rocks a similar series of eruptions, thus indicating a certain contemporaneity and analogy of circumstances of outflow. The three types of rocks found in these districts in the order of their appearance are: (*a*) andesites and green dacites, (*b*) rhyolites, and (*c*) labradorites and basalts.

Those of the first type have already been referred to as greenstones. They may also be described as andesitic porphyrites, chiefly of hornblende, and orthophyres, while some more nearly resemble the amphibole and pyroxene-andesites. All present similarities to the rocks described by von Richthofen

under the general name of propylites, which are well known in Hungary, Transylvania, Nevada, and from some South American localities. They present various aspects of the trachytic and trachyto-porphyritic structure, a different quantity and development of the elements of the first generation sometimes causing the microlitic magma to predominate over the amorphous. An idea of the various aspects which these rocks present can be given by mentioning some from different localities. Commencing with the dacitic types, one may note the rock which occurs at various points in the mining district of Parral, in the state of Chihuahua. It is dark green to dull green in color, and contains scattered crystals of transparent feldspar, together with hornblende that to the naked eye appears to be of a dark green color, and lamellæ of dark green mica. The magma is of a character in part microfelsitic and in part microlitic, with disseminated particles of yellowish green hornblende, which is the mineral which gives to the rock its color. The crystals of hornblende are in part decomposed and do not always preserve their sections. This alteration, either central or peripheral, consists of a transformation to calcite, chlorite and sometimes to epidote.

To judge by the free quartz which it sometimes contains, this rock bears some similarity to the felso-dacites of propylitic appearance, of Rosenbusch, and may correspond in part to the dacites as well as to the porphyrites of Fouqué and Lévy that are likewise analogous to some of the propylites described by Zirkel from the Virginia Range. In the same region these rocks sometimes have a lighter color owing to the abundance of disseminated feldspar crystals which give a more marked porphyritic appearance. There may also be observed with the naked eye and in very variable quantity, grains of pyrite disseminated in the paste.

In the region of Guanacevi, Durango, altered andesites of green color form the rocks of the first eruption. With these are associated superposed andesitic tuffs and sometimes rhyolitic tuffs, likewise green, in beds of considerable thickness which

always contain veins of epidote visible in thin layers. The greater number of the mineral veins of this locality occur in these rocks. In the state of Sinaloa these greenstones abound in many of the mining districts, but are more or less altered by the contact of the metalliferous veins, now gold, now silver-bearing. These microlitic greenstones pass sometimes to an ophitic structure, and even to holocrystalline rocks of clearly granitic structure giving types of diorites and diabases. In the territory of Tepic green andesites occur in great quantity, always with analogous characters. In the state of Jalisco green dacites occur at the mines of Los Reyes, San Sebastian, and Real Alto.

In Fresnillo and Sombrerete, in the state of Zacatecas, rocks of similar aspect are found covered by an extensive formation of rhyolite tuffs.[1] In the district of La Luz, state of Guanajuato, the small size of the mineral elements and the profound alteration which the rocks have undergone prevents usually an exact microscopic determination of the minerals or the rock structures. It is, however, possible in some cases to observe characters which show that the rocks approximate to andesitic porphyrites or hornblende andesites.[2] It is interesting to note that there exist great similarities between the rocks of La Luz and those associated with the rhyolite tuffs in the mines of the state of Zacatecas. The fine grain of the former rock has indeed caused it to be called a rhyolite tuff.

As regards the age of the formations of La Luz and those about the city of Guanajuato, various conclusions have been reached, owing to the absence of fossil remains in the sediments, as well as the complex nature of the eruptive regions of the vicinity. The rocks of the latter regions, which include the hornblende granites of Santa Ana and the granites of the Ser-

[1] The rocks classified as rhyolite tuffs are some of them andesitic tuffs which appeared during the eruptions of andesites, and were later impregnated with silica, while others were derived from the eruptions of rhyolites.

[2] The term porphyrite is restricted in use by Ordoñez, but is employed by him to designate Tertiary rocks differing slightly in appearance from the common andesites and showing peculiar alteration.

rania del Gigante, belong undoubtedly to a pre-Cretaceous epoch. Fragments of these granites, syenites, etc., occur in the red conglomerate of Guanajuato. They are undoubtedly anterior to the rocks of La Luz, which may be considered to be recent Tertiary.

In the metalliferous regions of Pachuca, Real del Monte, and El Chico, in the state of Hidalgo, altered pyroxene-andesites and dacites of green, dark and light gray, and violet color, constitute the predominating eruptive rocks. They are distinguished from the rocks previously cited chiefly by their structure, which may be considered as invariably trachyto-porphyritic; a structure produced by large crystals of labradorite and altered remains of crystals of pyroxene. Andesite tuffs like those of Guanacevi or rhyolite tuffs like those of Zacatecas scarcely occur at all. There are many other points along the Sierra Madre where the andesitic greenstones occur, chiefly in the states of Chihuahua, Sinaloa, Durango, Jalisco, and the territory of Tepic. From these the regions of Zacatecas, Guanajuato, and Pachuca are somewhat distinct from an orographic point of view. Considered petrographically, however, they are mountain regions which, on account of the order of eruption of their igneous rocks, may be regarded as branches of the Sierra Madre penetrating toward the interior.

Trachytes and trachyte-andesites have in some of the localities mentioned immediately succeeded the andesites, either as a modification of the latter or as a later eruption. Trachytes are, however, relatively rare in Mexico, especially among the earlier eruptives. They are more frequent before the second period of andesites and in the modern eruptions.

The rhyolites appeared after the andesites, presenting the variations common to rocks of this type. They occur in many localities, only the principal ones of which can be indicated. In the central part of the Sierra Madre the rhyolites cover great areas. Here the structure passes from the micro-granulitic to one entirely vitreous giving obsidians and retinites. The rhyolites are likewise notably abundant in many places of the Mesa Cen-

tral, where some of them may be considered of later age than those of the Sierra Madre.

In general it can be said that the forms of the mountains of rhyolites are always characteristic, serving in many cases to foretell their nature, especially when this rock occurs alone in an extensive portion of one serrania. Of those with sharp and elongated peaks we have a good example in the peak of Bernal in the state of Queretaro. The extended forms present us great cliffs (*acantilados*) in the extensive serrania of Valdecanas and in the no less interesting Sierra Fria in the state of Zacatecas.

In the second of these serranias, formed in great part of rhyolites, variations of structure and texture have brought about the formation of plateaus and dome-like summits and erosion has given rise to broken, fantastic shapes. In this sierra as in many other localities formed of the same rock, the spherulitic rhyolites of slightly coherent or tufaceous paste alternate in beds more or less horizontal or parallel with petrosiliceous rhyolites charged with quartz, which are compact and resist the forces of erosion. The result is an appearance of steps or stairs at different heights on the slopes of the mountains. The surfaces of the separated blocks, as a result of contraction or atmospheric action, generally have columnar or other imitative forms, such as are shown by some of the peaks called The Friars; a name by which rocks of columnar structure are designated in various parts of the country.

As notably spherulitic rhyolites can be mentioned those of Chichindaro, in the state of Guanajuato, and those of San Ildefonso, Tula, Hidalgo. There are spherulitic and perlitic retinites in Apaseo el Alto, which are of pretty appearance on account of the contrast of color which the gray or black amorphous paste offers to the generally red spherulitic globules. But the most abundant rhyolites are the petro-siliceous rhyolites of various shades, red, black, violet, etc., such as those of the Sierra del Jaral and other points in the vicinity of the regions of San Luis Potosi, together with those of Guanajuato, Pozos, Peñoles, etc. Some of the latter frequently are accompanied

by retinites, which may come to predominate, as in the hill Xicuco between Tula and Mixquiahuala of the state of Hidalgo. The violet-colored rhyolites that occur in flows in the Tertiary formations of the Acacico near Yahualica, Jalisco, are notable for the curious forms (axiolites) which the microfelsitic paste presents under the microscope; forms very similar to those which Zirkel describes in a rock from the Black Rock Mountains, Nevada.

In the central part of the country between the parallels 19° and 21′ N. Lat., a notable eruptive zone exists. In this zone the appearance of modern eruptives has commenced generally with the rhyolites, to which have succeeded andesites of a second eruption, a lesser number of trachytes and the labradorites and basalts which form the chief eruptions of the modern volcanoes.

The andesites of the second epoch always present characters by which they can readily be distinguished from those of the first. The orthorhombic pyroxene, hypersthene occurs frequently among the ferro-magnesian elements of the rocks, now as a principal and now as an accessory constituent. The microlitic feature so marked in the earlier rocks diminishes little by little and the proportion of the amorphous groundmass, always devitrified, is increased.

A grouping of the andesites by regions, subdividing them by varieties of structure or the predominating ferro-megnsian element, is not practicable on account of the constant change which occurs in the nature of the component minerals and degree of crystallization. The hornblende-andesites of a microlitic and felsitic magma sometimes containing quartz (dacites) appear to have been erupted immediately after the rhyolites in the second andesitic period. The dacites are anterior to the pyroxene-andesites, likewise of the second epoch, as is shown by the frequently observed superposition of the latter and by the thick sedimentary deposits which have covered the dacites. Alluvium with pebbles of dacite is also found at great depths in the interior of several of the valleys. The hornblende-andesites

are distinguished as a general rule from the hornblende-andesites of theformer epoch by the exclusive existence of gray hornblende with strong dichroism, altered often in the periphery of the crystals into ferruginous products. The colors which generally predominate are grayish-violet and red. The latter color comes from the alteration of the violet by the decomposition of the crystals of amphibole into oxides of iron which are disseminated in the groundmass. The majority are of trachyto-porphyritic aspect.

Contemporaneous with or perhaps previous to these andesites should be noted the greater part of the hornblendic or micaceous trachytes whose number is, to be sure, limited, especially if compared with the number of those which were considered trachytes before the application of the microscope. The presence of hypersthene in abundance in andesites marks the end of the andesitic eruption, since such andesites are seen alternating with the basalts of modern outflows.

Hornblende-hypersthene-andesites are found in abundance in many places. Such are localities in the sierra which bounds the valley of Mexico on the west, in the valley of Toluca and in some parts of the Sierra Madre of the state of Chihuahua. The vitreous types of these rocks and some dacites frequently occur. These present a vitreous magma having spherulitic and perlitic structures. Andesitic obsidians with amphibole or mica are found in dikes as intrusives in the valley of Mexico.

Passing to the andesites made up wholly or chiefly of hypersthene, two varieties may be distinguished: first, those having a largely microlitic groundmass, and, second, those in which the amorphous groundmass predominates (andesitic obsidians). In many localities the two aspects of structure are associated and the fact that they grade into one another shows that the differences arise from variations in the conditions at the time of eruption.

In the andesitic-obsidians the augite appears successively in the first and second generations and then under a quasi-crystal line form, that is, as a simple devitrification of the amorphous

groundmass, or even in very small microlites. The andesitic eruptions of our volcanoes have produced these vitreous rocks charged with pyroxene. Such may be seen in the lavas of the volcano Colima and the early eruptions of Popocatepetl.

While andesites of the vitreous types predominate in the more recent eruptions, trachytes of the vitreous type also occur. The lavas of 1870 thrown from the volcano of Ceboruco furnish us a good example of this and may be designated as obsidian-like pyroxene-trachytes. Vitreous trachytes are likewise found in the volcanoes of Popocatepetl and Colima.

The presence of olivine as an accidental element in these rocks gives them to the naked eye the appearance of basalts. With these they have sometimes been confounded owing to the similarity of color and superficially blistered appearance, common to the basaltic lavas. There can be no doubt that they pass from one to another by insensible gradations since the diminution of oligoclase with the absolute predominance of labradorite, brings them to basic types represented by labradorites and basalts. Such gradations may be actually observed in some places in the valley of Mexico.

After the hornblende-andesites, which seem to have succeeded the rhyolites, the eruptions continued not only by emission of compact rocks, but also by an enormous quantity of broken products that were changed to sediments by watery vapors of the same eruptions and by atmospheric agencies Thus have originated those thick deposits of andesitic tuffs, breccias, etc., which are so abundant in different portions of the great central valleys of the country. The more superficial layers, having the lightness and fineness of detritus, have indeed been confounded at times with æolian products.

Lastly may be noted the labradorites, that is, basalts containing no, or only accidental, olivine, and the true basalts which occur in the volcanic regions or in rare cases rest upon or break through the Cretaceous limestones.

Labradorites occur in contact with the andesites of the first epoch and rhyolites, at various points along the eastern slopes of

the Sierra Madre. Among these points may be mentioned El Parral, in the state of Chihuahua; El Nayarit, in the territory of Tepic; the eastern part of the state of Jalisco; and near the volcano of Jorullo in the state of Michoacan. The early age of these labradorites is indicated by the fact that olivine is rare or absent. In the modern labradorites it occurs with more frequency.

These labradorites frequently exhibit a columnar structure, the most striking example of which is seen in the famous columns, 130 feet in length, along the Barranca of Regla in the state of Hidalgo. These stand upon Tertiary tuffs, resting in their turn upon arenaceous Upper Cretaceous limestones. The labradorites are compact, of gray color, and contain scattered grains of olivine. Geodes of zeolites occur in the columns, chabazite being most common, while thomsonite and arragonite are also found. The later series of labradorites and basalts continued up to the latest volcanic eruptions. Examples are found in the mountains about the valley of Mexico, as in the Peñon de los Baños, where pyroxene-labradorites in thin layers exhibit curious undulations. In some lava flows near the volcano of Ajusco at the southern part of the valley occur labradorites formed simply by a marked diminution of the olivine in the basalts which predominate in the region.

The vitreous hypersthene-andesites which formed the larger part of the early volcanic outflows were succeeded by basalts erupted through new volcanic foci. These exhibit an abundance of olivine in a microlitic groundmass of labradorite and pyroxene. The outflow of basalts in turn ceased, however, and the field was left anew to the hypersthene rocks which characterize the lavas of the volcanoes now in activity. This alternation is illustrated by contrasting the olivine-basalts of Jorullo of the middle of the last century with the present outflows of Ceboruco and Colima which present good types of trachytes and pyroxene-andesites with vitreous groundmasses.

In the northern region of the country, over the Mesa Central and along various points of the eastern Cordillera Madre,

basalts occur cutting their way through Mesozoic sediments and covering the Tertiary eruptives. In the plain extending to the south of the Cordillera of Mazapil and in the portion between the mountains of Gruñidora and Ahorcados, Tertiary basalts come up through the schistose Cretaceous limestones and along the upper surface of the latter marked metamorphism has been produced by the contact.

After the work of eroding waters had filled the valley of Mexico and made it habitable by man, a mighty cataclysm devastated the southern part of the valley. A flow of basalt ten miles in length, accompanied by showers of ashes, came from the volcano of Xitli and buried much of the inhabited region. Hence in the layers of pumiceous tuffs upon which these lavas rest, numerous utensils of primitive industry, human bones and bones of other modern vertebrates are found. The volcano of Toluca had ceased activity at this time, but Popocatapetl continued to pour forth eruptions of hypersthene-andesites. The eruptions of the latter volcano ceased at the beginning of this century, and now only a solfataric activity exists. The same is true of the Pico de Orizaba.

About the middle of the last century a new volcano appeared in the Mal Pais in the state of Michoacan. Its products were black basalts highly charged with olivine. With this last volcanic phenomenon was closed the prolonged inundation of basaltic and andesitic lavas which began to make itself felt at the end of the Tertiary period.

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